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BALLOON-ELEVATED ANTENNAS

M. L. Leppert; F. J. Shanahan,
and D. A. Worsley

Communication Branch
Radio Division

February 10, 1955



NAVAL RESEARCH LABORATORY
Washington, D.C.

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ABSTRACT

Experimental investigations and research have shown that zeppelin-type balloons may be effective in elevating antennas for use aboard ships operating in the polar regions. Appropriate spooling equipment and the associated control and protective systems were developed. An emergency antenna lifting device has been developed which includes refinements expected to solve the problem of antenna entanglement in the ship's rigging. Operating procedure and handling techniques for the balloons are suggested.

PROBLEM STATUS

This is a final report on one phase of the problem; work on other phases continues.

AUTHORIZATION

NRL Problem No. R01-03
Project No. NE 121-021 Subtask 33
Bureau No. S-1741

Manuscript submitted January 5, 1955

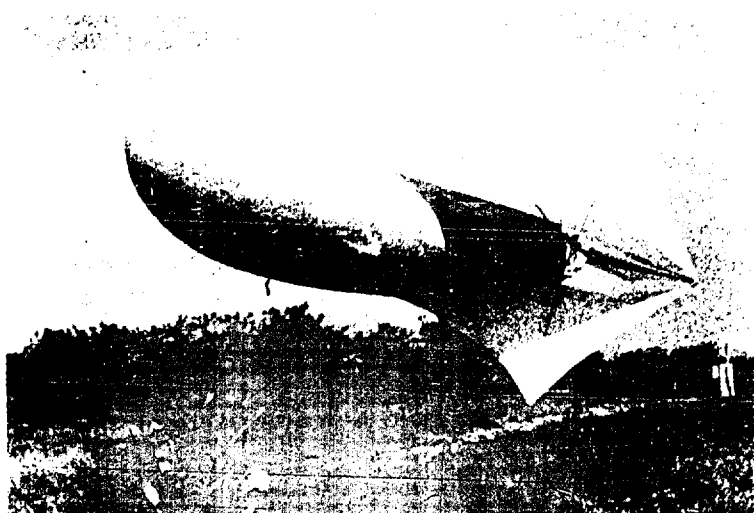


Fig. 1 - Dewey and Almy Chemical Company Kytoon

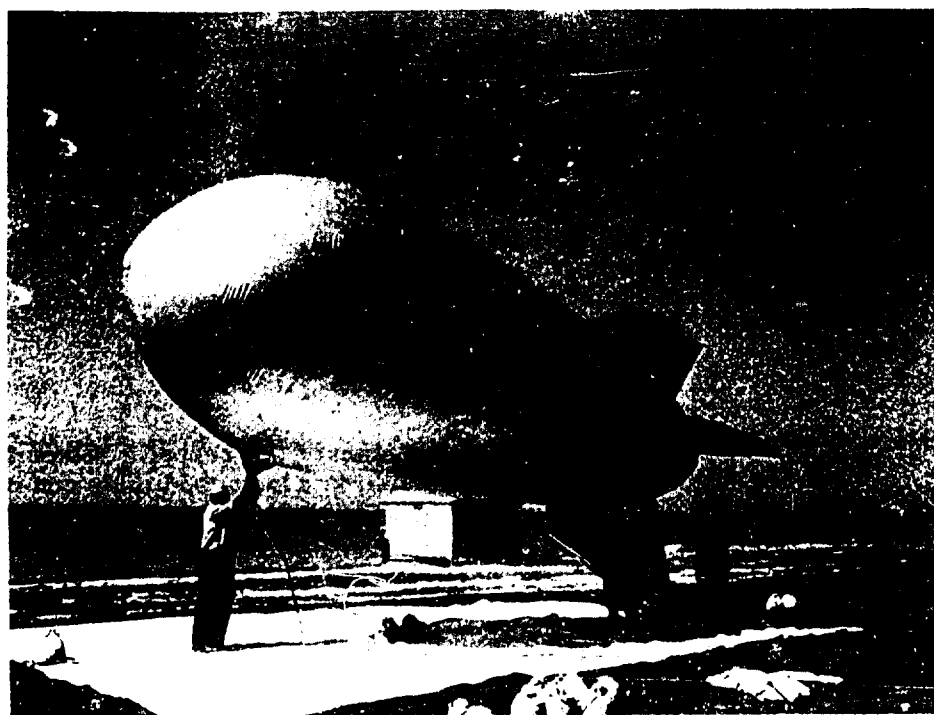


Fig. 2 - Goodyear zeppelin balloon

Flights were made in winds of various velocities and gustiness to determine the characteristics and behavior of a zeppelin-type balloon when used for an antenna lift and to find the requirements of a suitable cable spooling mechanism. In these experiments wind velocities were carefully measured in open space with a cup-type anemometer and line tensions were measured with a spring scale. The experiments were continued in winds of increasing velocities up to a point where the rigid stabilizers of the balloon were ruptured in mid air while in flight.

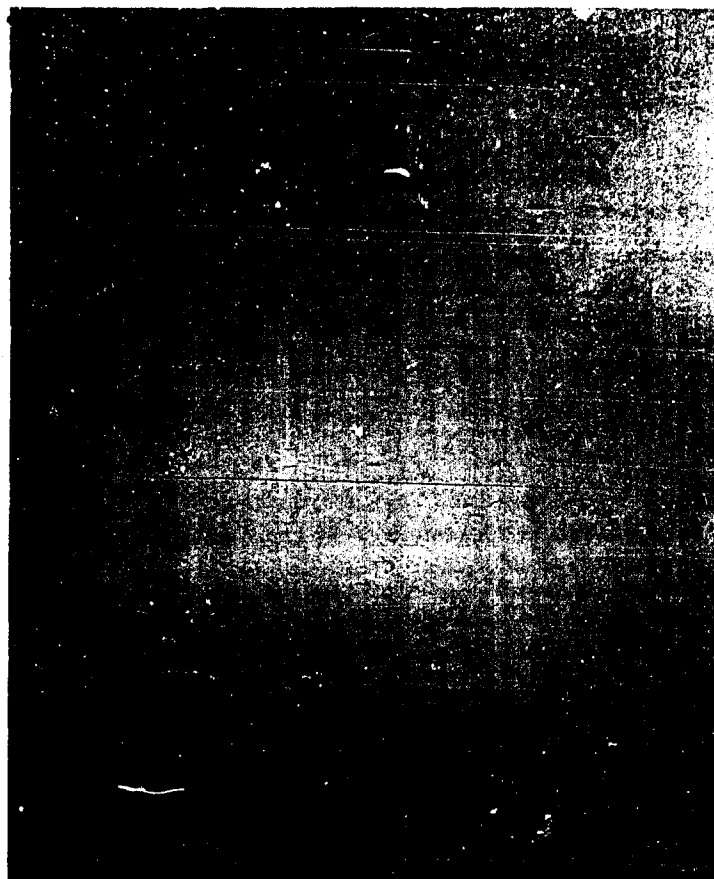


Fig. 3 - Zeppelin-type balloon with antenna

Various disadvantages were encountered with the Goodyear-type balloons. The rigid stabilizers are attached (Figs. 4 and 5) to the envelope of the balloon by snap fasteners and held in position by small cords which frequently break in flight due to friction and stress. Also, the stabilizer elements are difficult to attach during the inflation process, especially during windy conditions. Replacement of the upper stabilizer necessitates removal of the lower fin and a partial deflation of the envelope because the tail assembly is inaccessible after inflation to a person working at ground level. It was found that these stabilizer elements warp on exposure to moist air while the balloon is in flight or stored in an inflated condition.

Balloons are difficult to handle in windy conditions and they may be seriously damaged or lost by a single thoughtless act or careless handling in the gassing, launching, or retrieving. In these experiments it was found that a balloon could not be inflated and prepared for flight in an unprotected area when subjected to wind velocities greater than approximately 30 miles per hour. In winds of greater velocity the cement-attached appendages were ripped off and the balloon collapsed, subjecting the fabric to puncture by the high-velocity stream of helium used in filling. This finding was verified by flights from the deck of the Icebreaker EDISTO (AGB-2)¹ while operating in the Greenland-Iceland area, and by flights from the USS BURTON ISLAND (AGB-1).²

¹ Worsley, D. A., and Good, C. A., "Balloon Supported Antennas for Arctic Communication," NRL Memorandum Report No. 153, May 5, 1953

² "Bering Sea Expedition, USS BURTON ISLAND, AGB-1," August 19, 1954

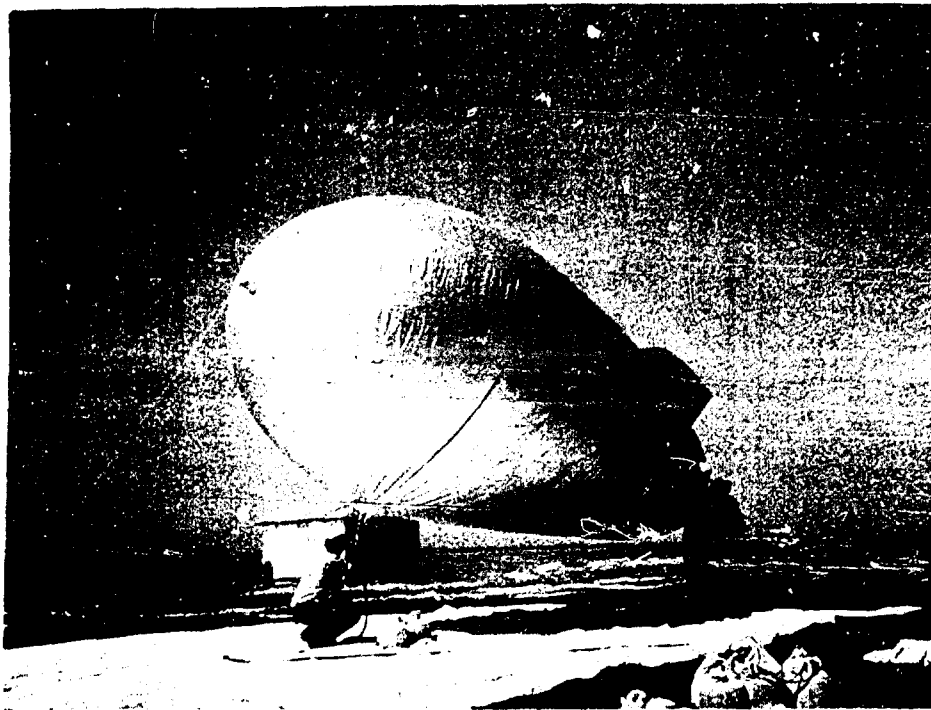


Fig. 4 - Attaching stabilizers to Goodyear balloon

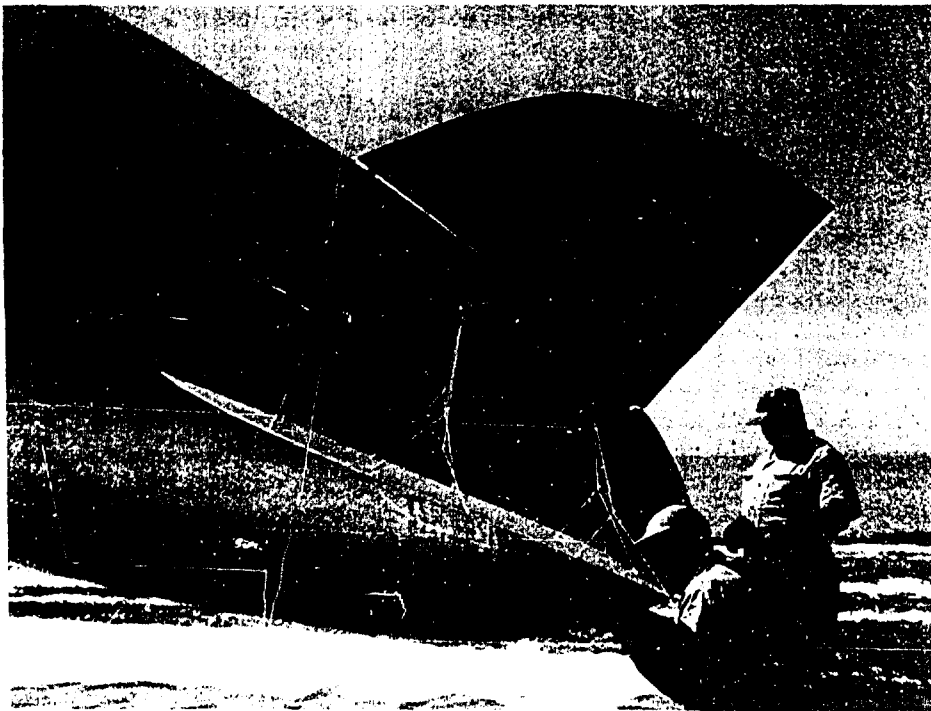


Fig. 5 - Rigid stabilizers of Goodyear balloon

In an effort to obtain balloons which could be rigged more easily from the small flight deck of an icebreaker and which would eliminate the difficulties experienced with rigid tail fin assemblies, balloons of the Jalbert Aerology Laboratory were secured to determine their flight characteristics. Several models were flown at the Chesapeake Bay Annex of the Naval Research Laboratory on a 1000-foot nylon cable, and the angle of the mooring line with the horizon was measured (Table 1).

TABLE 1
Jalbert Balloon Data

Model	Static Lift (lb)	Length (ft)	Diameter	Volume (cu ft)	Observed Angle (°)
JX-2	4	17	6'	284	50 - 53
JX-3	3	15.5	5' 10"	265	40 - 54
JX-5	6.5	18	6'	375	70 - 73
JX-7	13	20	6' 8"	525	30 - 85

The Jalbert JX-7 balloon (Figs. 6 and 7) was selected for flights to be made from the deck of the EDISTO while cruising in the Greenland-Iceland area. This balloon is equipped with hinged, semirigid, cloth tail fin assemblies which are permanently attached and held in position by elastic shock cords. They are rigged by inserting the ends of two crossed wooden struts, placed horizontally and vertically, in pockets at the extremities of the fins (Fig. 8). A third strut, positioned axially, is attached by a cloth hinge to the middle of the horizontal strut, and its aft end is inserted in a sling which is formed at the ends of the fins. Since the fin assemblies are held in position by elastic shock cords attached to the balloon, they may fold on hitting an obstruction. This type construction minimizes warping and breakage of rigid members. Should the wooden struts be broken accidentally in rigging or launching, replacements may be made easily in the field. Flying and handling qualities of the balloon are good and it may be rigged and prepared for flight more easily in limited space or under adverse weather conditions. The rigging is arranged so that the balloon may be trimmed to obtain maximum dynamic lift which may exceed the static lift.

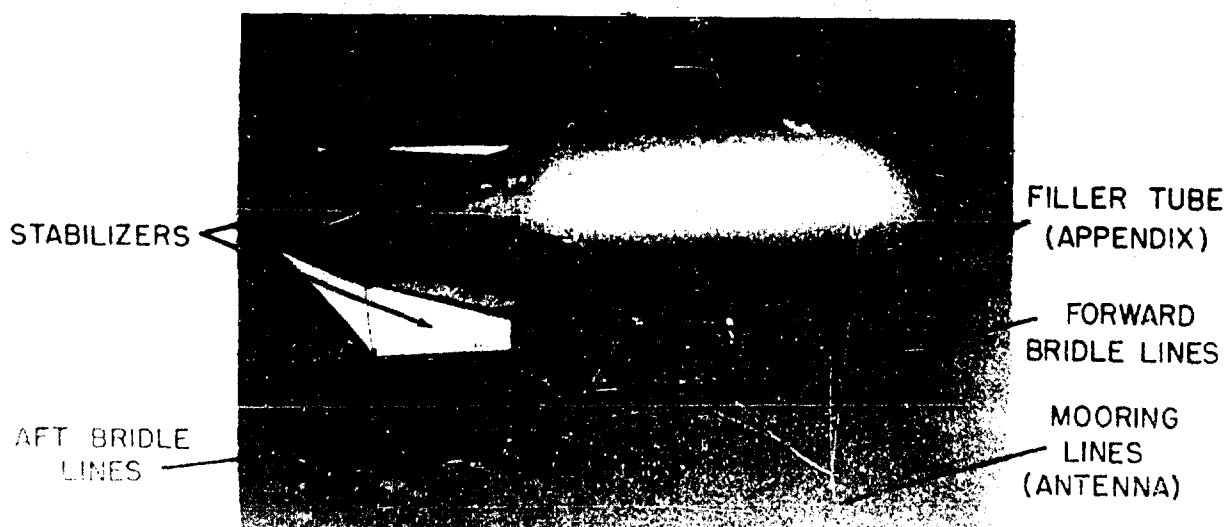


Fig. 6 - Jalbert JX-7 balloon



Fig. 8 - Tail assembly of JX-7 balloon



Fig. 7 - JX-7 balloon with antenna

Although the JX-7 balloon will supply the lift necessary to elevate a 1200-foot length of 1/8-inch antenna cable in moderate winds it is recommended that a balloon of somewhat larger gas capacity be used to increase the antenna angle. Should even greater lift be desired, it may be obtained by the use of a cluster of two or three balloons abreast (Figs. 9, 10, and 11). Experience has shown that it is easier to inflate and prepare for flight two or three small balloons than a single large balloon of the combined gas capacities. For operation under adverse conditions when high winds and rough seas make gassing and rigging difficult, the operator may prefer the multiple balloon arrangement.

In order to obtain further information on the handling of a balloon from limited deck space, recent experimental flights were made from Tilghman Island, Chesapeake Bay Annex. An area of the same dimensions (26 by 52 ft) as that available for flights on the Icebreaker GLACIER (AGB-4) was staked out adjacent to a tower which simulated the mast. Then the operations of gassing, rigging, launching, and retrieving were carried out using balloons up to 25-1/2 feet in length and 9 feet 11 inches in diameter. The operations were successful and it is believed that this space is ample.

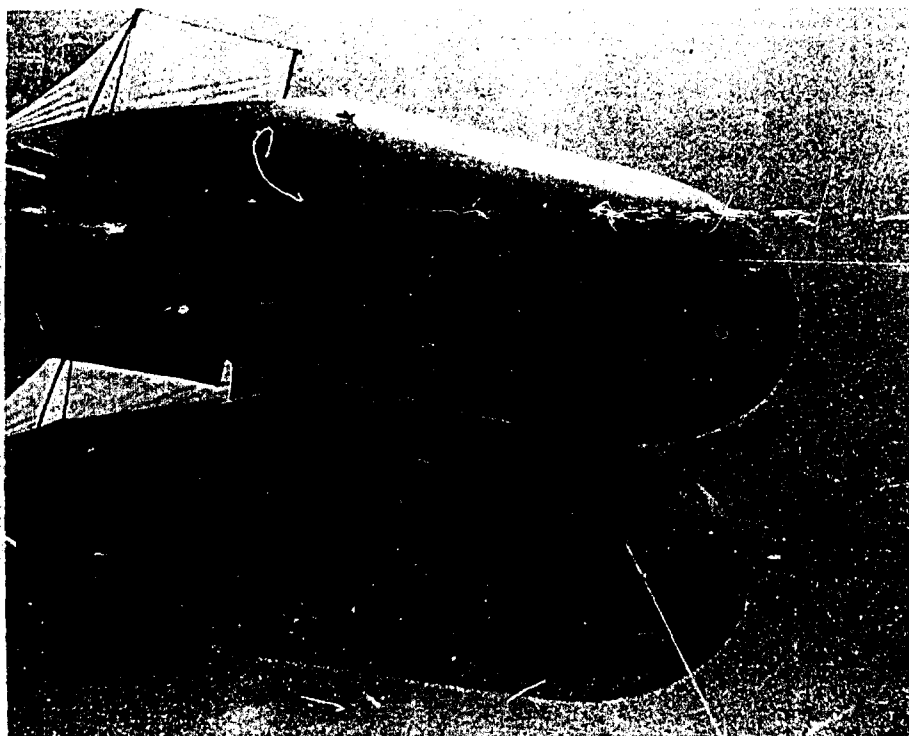


Fig. 9 - Bridle arrangement for two JX-7 balloons

POWER-OPERATED WIRE-ROPE REEL

In the early balloon experiments a small variable-speed winch powered by a 1/3-hp electric motor was used to spool the cable. Since this motor was capable of hauling in the balloon only at low speeds, it was replaced by a 1-hp motor (Fig. 12). Many measurements were taken of the power demand of the motor at different wind-in speeds over a wide range of measured wind velocities. Flights were made at the Chesapeake Bay Annex in wind velocities up to 18 knots with gusts of higher values. At times, tension in the mooring cable for the large balloon exceeded the capacity of a 100-pound spring scale. Later flights were made from the deck of the Icebreaker EDISTO in winds of velocity up to 28 knots relative to the ship.

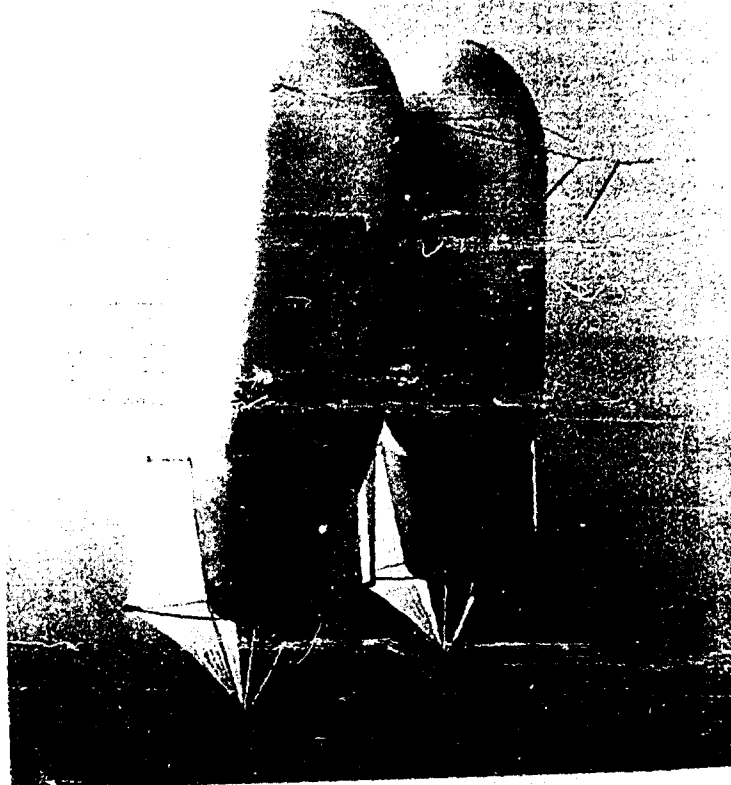


Fig. 11 - Flight of JX-7 balloons abreast



Fig. 10 - Adjustment of rigging for JX-7 balloon operations in clusters

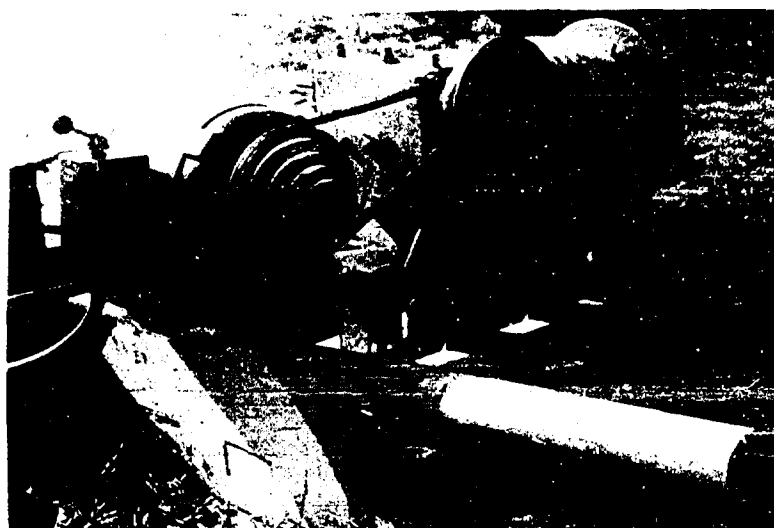


Fig. 12 - Experimental winch

These experiments showed that the 1150-cubic foot balloon could be brought in without undue strains or precautions at speeds up to 360 feet per minute under conditions of moderate winds. Therefore, the balloon could be retrieved in approximately three minutes at this speed, which would be fast enough for any emergency operation. Later, dead-weight loads were hoisted over the range of speeds of the motor-driven winch and the power demands were measured (Fig. 13). These experimental data indicate that a 2-hp motor would provide adequate wind-in power under all the wind conditions in which the balloon may be flown safely.

To fill the requirements of this problem, the antenna spooling equipment should be powered by a 2-hp electric motor. It should be capable of withstanding cable tensions up to 150 pounds and provide for reversible, multispeed operation at 90, 180, and 360 feet per minute. Also, it should include a level wind mechanism and a magnetic brake to stop and hold the cable. The control switch should be operated by a lever from a point outside the guard rail. The operating handle should be insulated for 20 kv and the equipment should be of watertight construction and capable of operation in temperatures as low as -30°F . Provision should be made for connecting the transmitter to the antenna cable spool either continuously by wiping contacts or by a magnetic contactor when the spool is stationary. The entire spooling equipment must be insulated from ground to withstand rf potentials up to 20 kv.

A search of the commercial market was made to obtain spooling equipment which would fill these requirements but none was available. It was found, however, that standard stock components from several power winches, with modification, could be incorporated into a power-operated wire-rope reel (Fig. 14) which would satisfy the requirements of the balloon-hoisted antenna problem.

These basic stock components, together with the associated equipment, were obtained by NRL and designed into a system which it is believed will prove satisfactory under the severe operating conditions of an icebreaker.

A list of the drawings from which the above and the associated equipment were constructed is given in Appendix B.

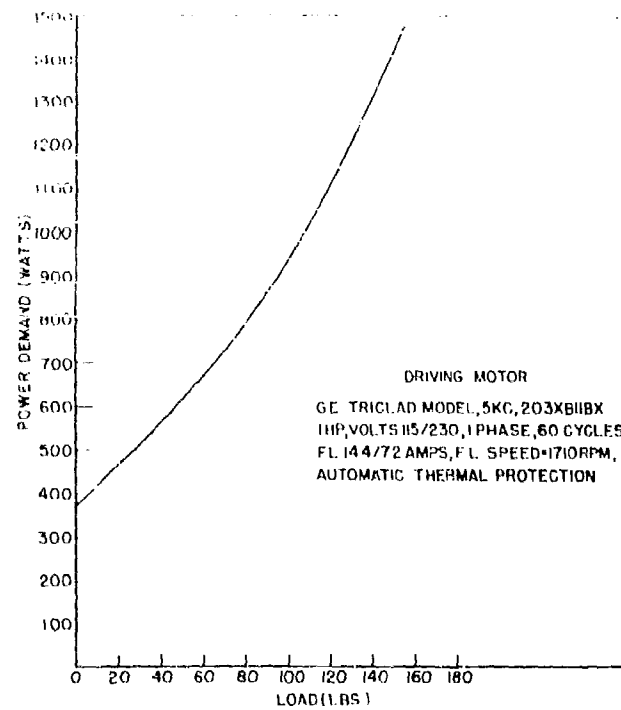


Fig. 13 - Calibration of experimental power-operated wire-rope reel at third speed (131 ft per min)

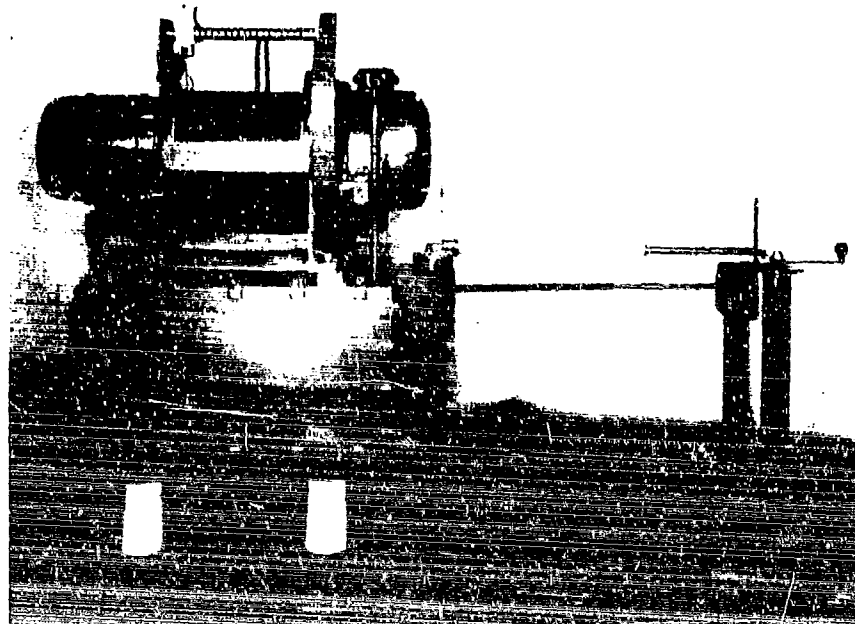


Fig. 14 - Spooling equipment with controls

This spooling equipment, including the controls, has been constructed and preliminary field experiments show very satisfactory operating characteristics even with three balloons attached to the antenna cable. A continuous connection is made to the antenna cable by a slip ring and brush assembly at each end of the supply spool.

ANTENNA AND POWER SWITCH

The switching equipment (Fig. 15) was designed for mechanical remote control to protect the operator from high voltages. Radio-frequency power is fed to the antenna by means of a curved section of copper tubing which connects the switch to the spooling equipment. The three-phase power leads to the driving motor are run inside this copper tubing to minimize the rf pick-up. Provision has been made for automatically grounding the reel and antenna circuit when the three-phase power is applied to the spooling equipment in order to prevent high voltage (rf or static) from appearing on the reel or feeding back into the power line while launching or retrieving the balloon. The transmitter feeding the antenna is protected from operating into an open circuit by the inclusion of an interlock which is actuated when the antenna disconnect switch is opened. For shipboard use it is recommended that the installation be enclosed within guard rails.

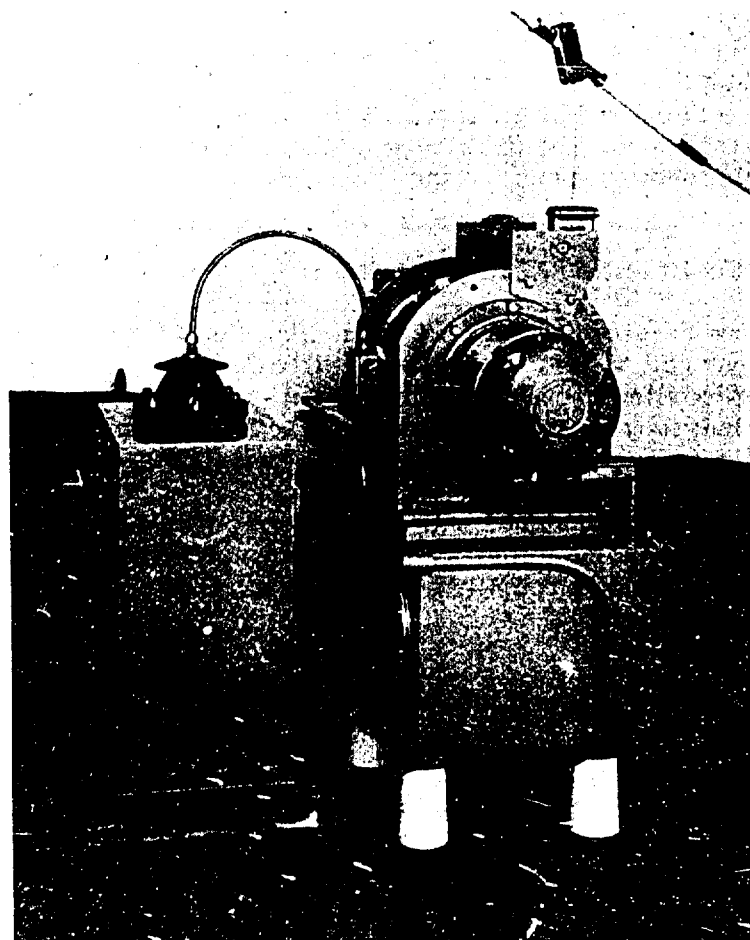


Fig. 15 - Antenna and power switch connected to spooling equipment

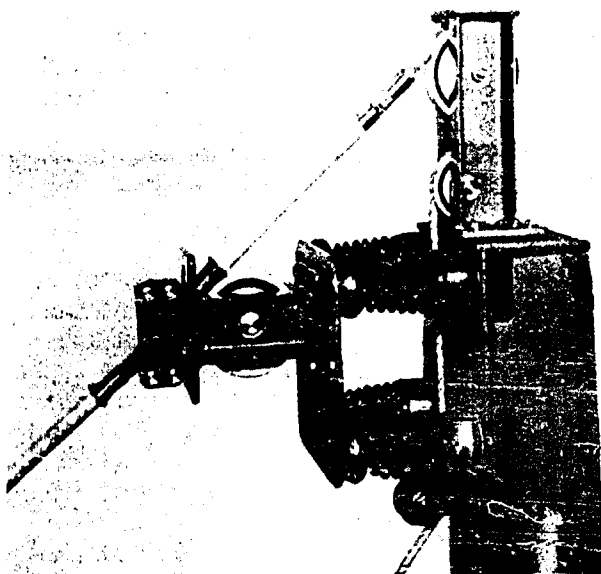


Fig. 16 - Antenna trolley and masthead sheave

ANTENNA TROLLEY AND MASTHEAD SHEAVE

To facilitate launching the balloon in adverse wind conditions from the deck of a ship, an antenna trolley and masthead sheave were designed and constructed (Fig. 16). This arrangement minimizes the danger of antenna entanglement in the ship's rigging and permits the pivot point of the antenna cable to be shifted to a clear, open space during the launching or retrieving process and to the top of the mast during balloon flights.

In operation, the antenna cable passes up from the supply spool between rollers in the trolley to an insulator which is attached to the rigging of the balloon. The trolley is attached by insulators to the handling lines, one of which runs through the masthead sheave on top of the mast then down through a pulley located near the base of the stack and aft to a capstan on the flight platform. The other line runs aft to a pulley near the stern end of the flight platform, then forward to join the first line at the capstan. The trolley may be positioned at any location between the mast and the aft end of the flight platform by means of the handling lines.

POLYESTER GLASS LAMINATED INSULATORS

Insulators were required to isolate the handling lines from the antenna trolley and to insulate the upper end of the antenna from the balloon. In this application they must be light yet strong to withstand the tugging stresses imposed by a balloon aloft in a buffeting wind. Also, they must have a low loss factor, be nonhygroscopic in character, and withstand radio-frequency potentials up to 20 kv.

These insulators were designed with special end fittings and were constructed at NRL of laminated glass fabric impregnated with polyester resins. They have satisfactorily withstood breakdown potentials in excess of 25 kv (rms) of radio frequency and have a low loss factor.

ANTENNA WIRE-ROPE CABLE

Since the balloon mooring cable must also serve as an efficient transmitting antenna, a lightweight cable of good electrical conductivity is required. The cable should be lightweight so that a balloon could elevate a 1200-foot length to a satisfactory angle for a good antenna and it must be strong to withstand the loading imposed by a balloon flying in gusty winds. It should be of sufficient diameter to keep the rf potential gradient to a reasonable value and minimize corona loss. The cable should be flexible and nonkinking, and should possess good wearing qualities to withstand repeated operations without breaking strands.

A $6 \times 6 \times 7$ wire-rope cable of phono-electric bronze was selected to fill the requirements of this problem. This cable has a nominal diameter of 0.125 inch with nylon strand cores. It has a breaking strength of approximately 335 pounds and weighs approximately 20 pounds per 1000 feet. Three 1250-foot lengths of cable are supplied with the equipment.

RADIO-FREQUENCY CHARACTERISTICS OF A BALLOON-SUPPORTED ANTENNA

Measurements were made of the radio-frequency resistance and reactance characteristics of one of the balloon-supported cables during the experiments performed at Tilghman Island. The cable used was a 7 by 7 wire rope consisting of six strands of seven No. 25 B & S gage (0.0179 in.) aluminum alloy 56S wires layed around a center strand of seven No. 24 B & S gage (0.0201 in.) 18 & 8 stainless steel wires. This combination of aluminum and stainless steel provides a lightweight cable of high conductivity, good corona resistance, and adequate strength. This particular cable was not recommended for use as a balloon antenna because of mechanical failures (poor abrasion resistance and kinking) but the measurements provide representative values of resistance and reactance.

The balloon was tethered to the antenna cable by means of a 3/4-in. diameter nylon rope insulator (Fig. 17). A ground connection was run from the measuring equipment to a 6-foot copper-clad stake driven into the ground approximately one foot from the water of the bay. As can be seen in Fig. 18, the winch was insulated from ground by four large porcelain insulators. The effect of the 80- $\mu\mu\text{f}$ capacity to ground of the winch is included in the measured data. The instrumentation consisted of a Navy type RBA receiver, a General Radio type 1001A signal generator, and a General Radio type 916AL impedance bridge.

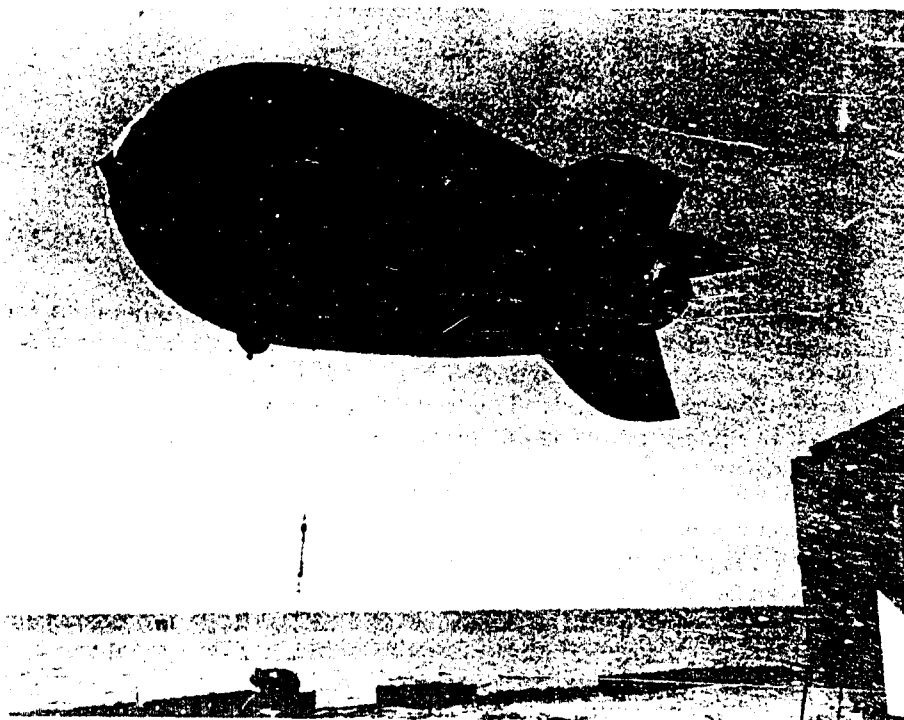


Fig. 17 Balloon tethered to antenna cable

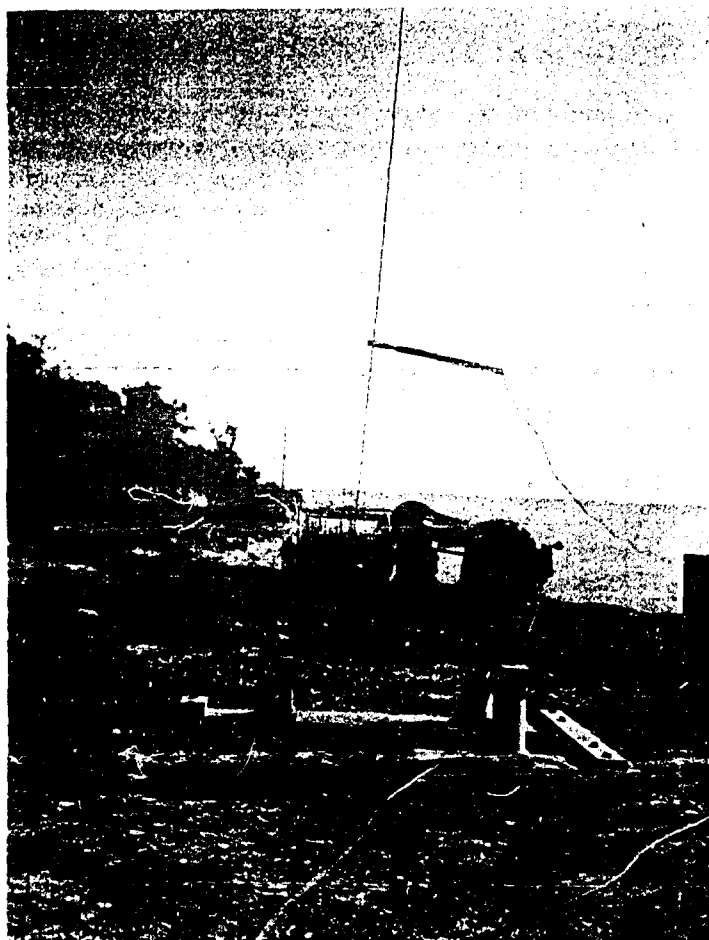


Fig. 18 - Winch and connecting lead between antenna cable and measuring equipment

Impedance measurements (Figs. 19 and 20) were made at frequencies from 90 to 220 kc with cable lengths of 800, 1000, and 1200 feet. Similar data were calculated, following the procedures of NRL Reports R-1671³ and R-1734,⁴ for the phono-electric bronze cable presently recommended. These data agree within 10% of the measured data, so that the latter should prove representative of values which will exist under actual shipboard conditions.

Anticipated antenna system efficiencies, taking into account load coil losses for an assumed coil Q of 300, are plotted in Fig. 21, along with the antenna feed point voltage, for varying antenna height and a frequency of 150 kc. These data indicate, for a cable height of 1000 feet, a radiated power of 1500 watts for a transmitter power amplifier output of 2 kw. This combination should provide a communication range of 1500 miles under northern latitude conditions.

³ Christenson, C. W., and Norgorden, O., "Notes on the Calculation of Capacity of Intermediate Frequency Antennas," NRL Report R-1671, December 1940

⁴ Norgorden, O., "Notes on the Analysis and Measurement of Intermediate Frequency Shipboard Antenna Systems," NRL Report R-1734, May 1941

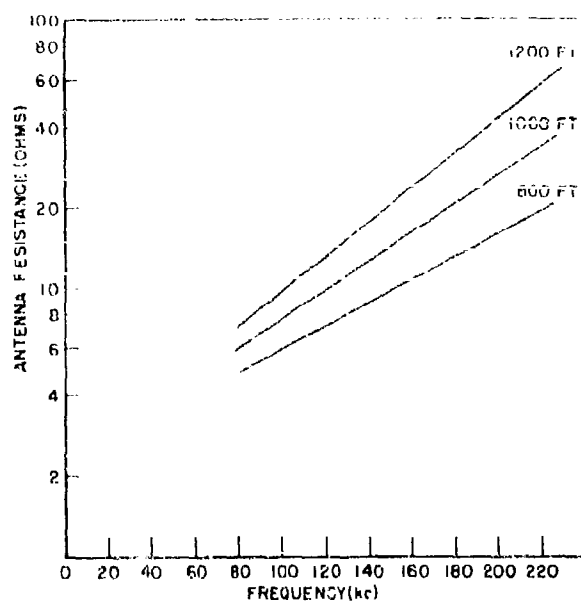


Fig. 19 - Antenna resistance vs. frequency

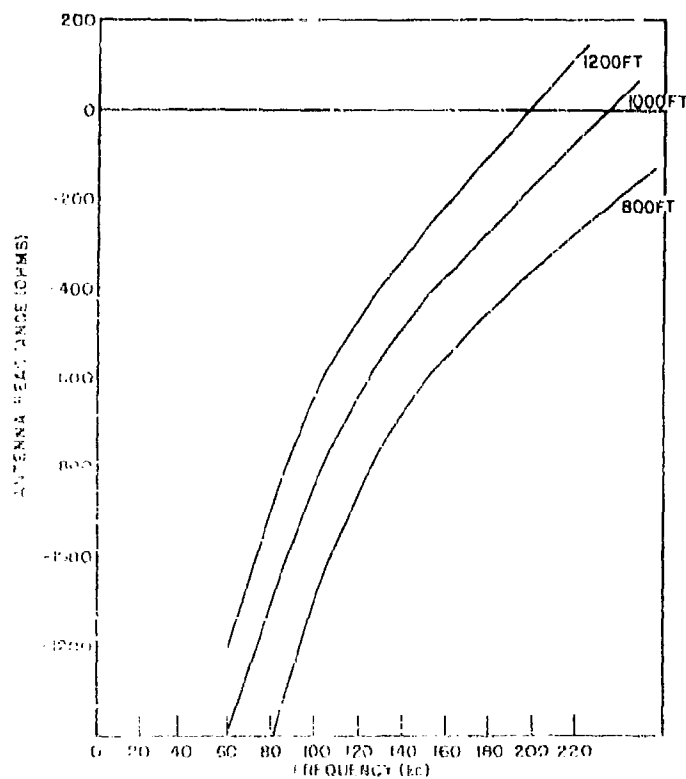


Fig. 20 - Antenna reactance vs. frequency

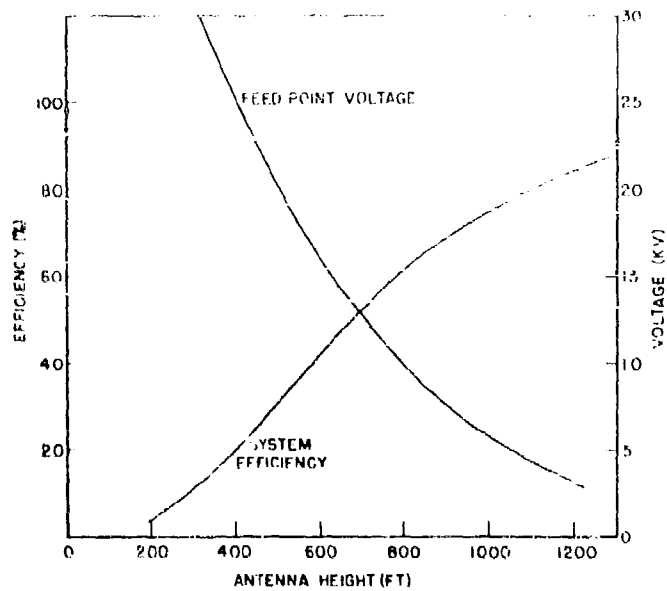


Fig. 21 - Antenna system efficiency and feed point voltage vs. height

ACKNOWLEDGMENTS

Grateful acknowledgment is made of the assistance and suggestions made by personnel of the Bureau of Ships.

Appreciation is hereby expressed to the personnel of the Chesapeake Bay Annex and the Tilghman Island Station for their willing assistance at all times.

* * *

APPENDIX A

Balloon Handling Techniques

1. The balloon should be stored in a warm place until it is time to start the inflation since cracking and damage to the neoprene-coated balloon fabric usually results if it is handled while cold and stiff.

2. Before the inflation and rigging processes are started, the flight deck should be covered by a tarpaulin or canvas cloth to protect the balloon fabric from being pierced by splinters or slivers of ice.

3. Whenever balloon-elevated antennas are to be used on shipboard, it is strongly recommended that a group of men be instructed in the proper handling of a balloon and that these same men handle all flights. Almost certain failure will result unless each man thoroughly understands his duty in the operation. Inattention to even the smallest detail may result in serious damage to the balloon or its loss. These men should be cautioned that the fabric must never be stepped on nor touched with finger nails and should be handled only with the fleshy part of the fingers.

4. It is advised that a 3/4 to 1 inch hose be used in the inflation process and its open end should be fitted with a cone diffuser to minimize the danger of blowing a hole through the fabric.

5. The struts to hold the stabilizer fins in place should be inserted when the balloon is approximately 3/4 full of gas (Fig. 8). After these struts are in position, the elastic shock cords holding the stabilizers may be fastened and the inflation completed.

6. Prior to launching the large balloon, it is recommended that a small balloon, such as the Kytoon by Dewey and Almy Chemical Company (Fig. 1), be flown at various altitudes to serve as a dependable wind-direction indicator and to predict the flight path which will be taken by the large balloon on launching. Another useful purpose is to indicate the buffeting to which the large balloon will be subjected by changing, gusty winds.

7. In launching the balloon, it is recommended that it be released rapidly to an altitude of at least 75 to 100 feet before stopping to check its riding characteristics. This procedure permits a quick passage through the turbulent hot stack gases in which the flight behavior is unpredictable. In addition, the effects of roll and pitch of the ship are less likely to jerk the balloon down to the deck or throw it into the guard rail around the flight deck.

8. With moderate winds additional dynamic lift may be obtained from a single balloon by shortening the aft bridle lines. This will permit the balloon to ride at an increased angle of attack which will increase the lift. Should additional lift be required at times of dead calm, it may be obtained by operating two or more balloons abreast (Fig. 11). In this arrangement both loops of the bridles are connected to the mooring line. The clove hitch on the forward bridle lines is loosened and adjusted until the horizontal stabilizer of each balloon is horizontal and parallel after which adjacent stabilizers are securely fastened together as shown in Fig. 9.

9. As a word of caution, a balloon should never be left in the air unattended. Although it may have been inflated to the proper pressure on release, the balloon may run into a "cold front" causing the gas to contract, thereby reducing the internal pressure. A "cup" is formed in the nose of the bag by the forces of a head wind and the spilling of the cupped wind causes the balloon to dart in any direction.

* * *

APPENDIX B
Design Drawings

Copies of the following design drawings may be obtained from NRL:

1. RA 10D 1371 (13 sheets) Power Operated Wire Rope Reel - Sub Assembly and Details
2. RA 10A 1371A (7 sheets) Power Operated Wire Rope Reel - Bill of Materials
3. RA 10D 1382 (12 sheets) Power Operated Wire Rope Reel - Control Unit Housing
4. RA 10A 1382A (7 sheets) Power Operated Wire Rope Reel - Bill of Materials
5. RA 24D 262 (20 sheets) Antenna Power Switch
6. RA 10D 1534 (4 sheets) Masthead Sheave for Antenna Guy Lines
7. RA 10D 1536 (1 sheet) Trolley for Balloon Antenna
8. RA 10D 1535 (1 sheet) Insulators for Balloon Antenna
9. RA 10D 1537 (1 sheet) Connectors for Manila Rope Guy Lines
10. RA 7D 216 (1 sheet) Icebreaker AGB-4 Emergency Antenna Winch Installation
11. Wiring Diagram - Motor and Controller
12. General Instructions for Electric Wire Rope Hoist - Installation, Lubrication, Adjustment

* * *